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# **Development of Rotary Compressor for Semi / Trailer Truck Applications**

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## **ABSTRACT**

This paper covers the design aspects of a compressor developed for a semi trailer truck application. The compressor developed for this purpose was a rotary vane compressor. This paper discusses the challenges of the design and the methodology adopted for overcoming them.

## **INTRODUCTION**

In response to the demand for a durable compressor for a Semi trailer truck application, a rotary vane compressor was developed. The unique demands included :-

- Life in miles, over twice the requirement for passenger vehicles.
- Extended compressor ON hours.
- Extended idling with air-conditioning on, (i.e. extended operation under high pressure conditions).
- Excessive vibrations.
- Larger cabin space.

This paper discusses unique features of the compressor. It also covers the steps followed to achieve the performance and durability requirements. These are listed below:

- Robustness tools to optimize the design
- Special mechanism.
- Special port design.
- Coatings.
- Selection of material / alloys.
- Shaft treatment.
- Special clutch design.
- Special oil circulation.
- Special machining of the rotor.

The performance & durability targets set for this compressor have been met.

## **OPTIMIZATION OF THE DESIGN PARAMETERS**

Robustness tools were used for designing the compressor. A three step approach outlined below was used:

- Concept design.
- Parameter design.
- Tolerance design.

### Concept design:

- Various architectures and technologies were examined for a variety of characteristics. These included cost, manufacturability, functional performance and durability. One concept was chosen to achieve the desired function of the product.
- Innovative ideas were encouraged, developed.

### Parameter design

- A Design of Experiment was run, having selected the optimum values for control factors that will reduce the variability of response to noise, Huang et al [1].
- Selected optimum values for control factors that reduced variability of response to noise.
- Selected optimum values for control factors to shift the mean of the response toward the target

### Tolerance design

- Significant characteristics were identified.
- Tolerances were decided on the basis of the Design of Experiment.

## **NOVEL MECHANISM**

A high durability 2 stage rotary vane type compressor was used, Figure # 1 illustrate the schematics. The compression occurs within the first and second stage chambers. Each stage has two balanced chambers which are defined by the vanes, rotor and housing.

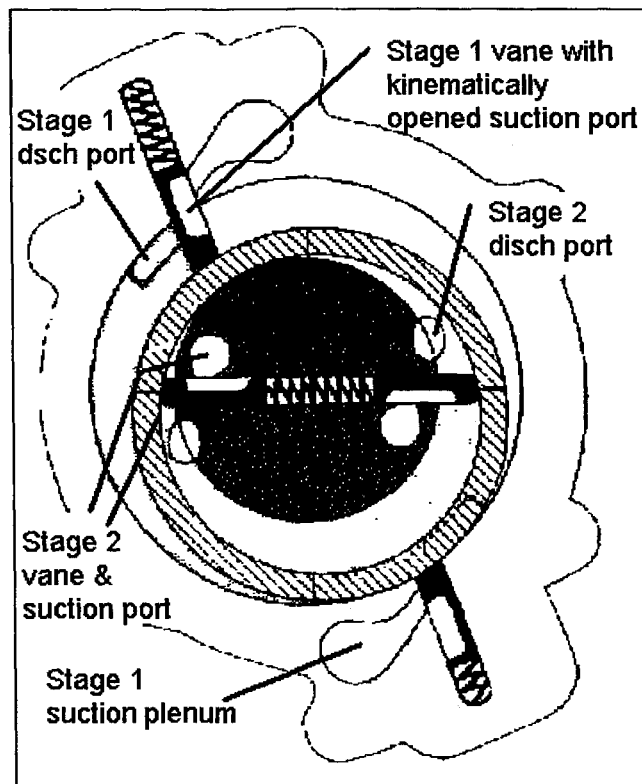


Figure 1: Cross-section of the compressor showing the inner and outer stages

## IMPROVED WEAR LIFE

Areas that were highly susceptible to wear were identified in testing. Special design features, materials and coatings were adopted to reduce wear in those areas. This sections covers some of these unique features:

### Port design

Schematic figures #2a and 2b show the original and improved port designs. The original port (Figure 2a) was designed initially for manufacture. When casting the post for the second stage vanes, the port was designed to be a cast in feature. Machining of the center slot opened the port. Unfortunately however, this meant that the lower vane support was reduced. Also, due to manufacturing difficulties deburring the port, the vane often experienced sharp edges. During high pressure operation, the overall effect was to wear away the vane coating resulting ultimately in failure.

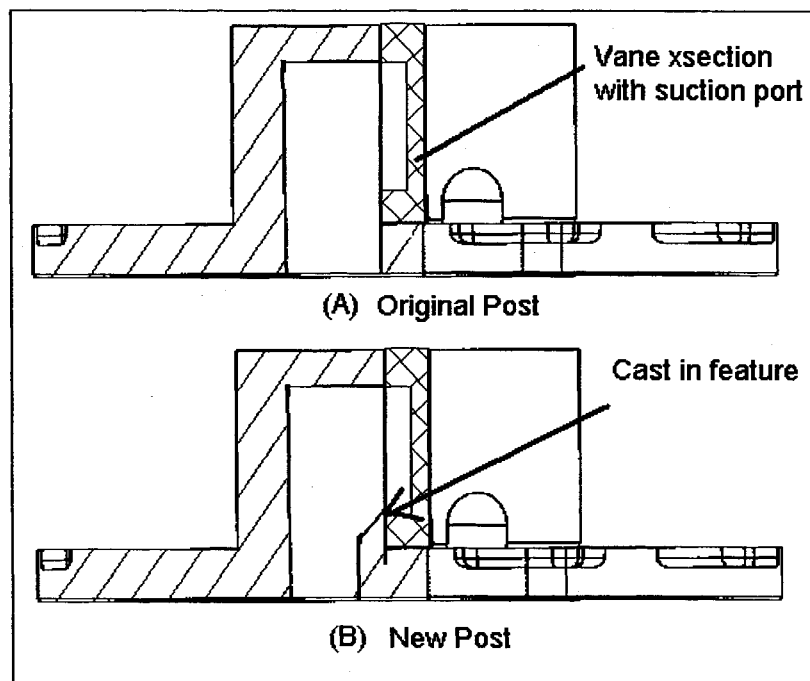


Figure 2: Modifications to post to improve wear durability

The solution to this problem was found, as shown in figure 2b. As the post was a sand cast part, it was possible to create a 90 degree lip at the port. This turned out not to be a major problem in manufacturing. The result was improved support for the lower edge of the vane, and the elimination of having to run the vane over a sharp lip. Significant improvement in the life was observed. See table 1 below:

<b>Vane slot design</b>	<b>Life, under accelerated high pressure test.</b>
<b>Normal port</b>	up-to 100 hours
<b>Special port</b>	>900 Hours
<b>Requirement</b>	890 hours.

Table 1: Comparison of accelerated durability test for new and old designs

### Coatings:

Some of the components needed special coatings:

- Vanes: The vanes needed to be light to avoid the problem of vanes not following the rotor. They also needed to be strong to sustain the pressure loading seen. Aluminum vanes had the appropriate characteristics, except in the area of wear resistance. An electro-less nickel boron coating N600 / N 700 was adopted for the vanes.. This coating had superior wear & scuffing resistance. The hardness of this coating is ~900 HV. N600 showed better wear properties than N700.

- Rotor: The rotor and housing of the compressor were aluminum alloys. They were not ideally matched for wear resistance. Due to their motion however and their ability to form appropriate lubrication films, under the majority of operating conditions material incompatibility was not a problem. Under starved lubrication conditions however, this form of contact was fatal for the compressor. The phenomenon of migration causes this condition. It is a common failure mode seen in automotive applications compressors, Bin and Churgay [2]. A soft tin (Sn) coating for improved surface lubricity was chosen. It effectively protected the rotor and housing under the loading conditions seen.

#### Materials / heat treatment

The following components required special attention to material & heat treatment selection.

- Shaft: The shaft ran against needle roller bearings. The size limitations did not allow the use of larger bearings. The predicted life of the untreated shaft with feasible size bearing was 25% of the requirement. The treatment adopted for achieving the desired life was as follows.
  - Case carburized SAE 8620 with low retained austenite for better wear resistance.
  - Isotropic surface finish for reducing wear.
- Rear plate: As seen in the discussion of the rear plate post above, it saw some large loading from the inner vanes. Special alloy additions and heat treatment were required to ensure a maximum of 5 % free ferrite.

#### Oil circulation:

Oil circulation in the pump was important to cool the oil. The bearings and inner vanes were out of the main flow areas of the pump. They required special attention. Appropriate oil circulation paths were designed into the compressor. These passages were optimised accordingly using the following methodologies.

- Identification of critical areas requiring the lubrication.
- CFD and flow analysis.

#### Special Machining of the rotor:

The rotor of the compressor experienced cyclical pressures across it. To enhance the fatigue life of the rotor, a special process was developed for machining the undercut. The aim was to have compressive stresses in the undercut area rather than tensile. Figure # 3 below shows the critical area where special care was taken.

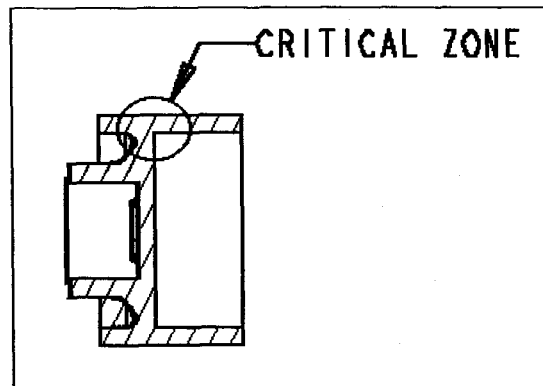


Figure 3: Region of fatigue failure weakness and area of improved stress reducing undercut

Table:2 below shows the impact of process on the residual stresses in the critical zone, as also the fatigue life improvement.

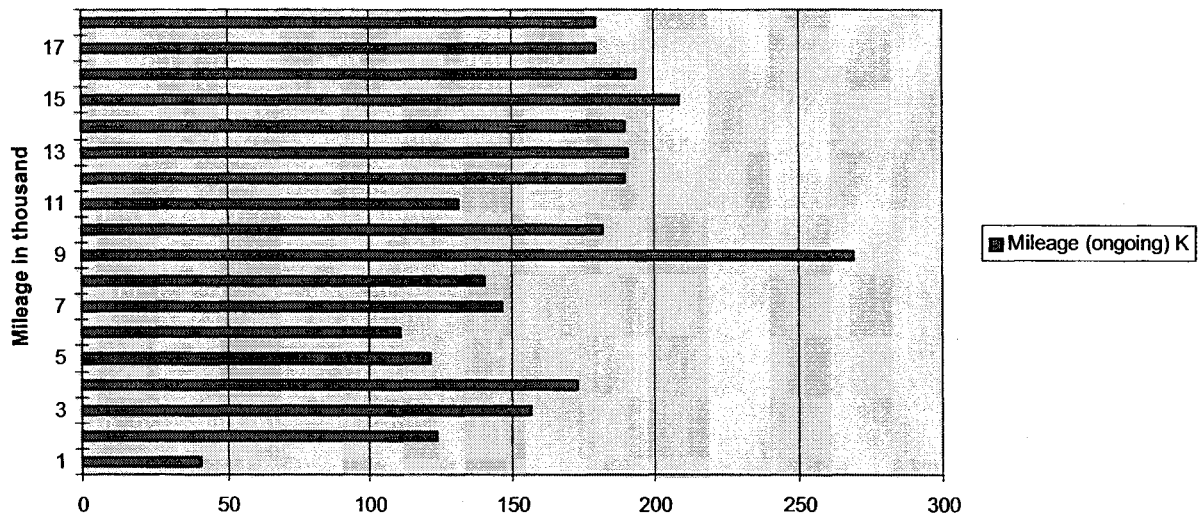
Process type	Residual stress ksi	life
<i>before improvement</i>	upto 14 tensile	1
<i>improved undercut forming</i>	upto 3 compressive only	>240

Table 2: Comparison of accelerated durability test for new and old undercut designs

## FLEET TESTING RESULTS

Incorporating the design changes mentioned above, a highly durable compressor was developed. A miniature fleet of 18 commercial semi-trucks is ongoing. The actual running time on the fleet is depicted below. So far the results are encouraging. The trucks have accumulated significant mileage.

Actual running time on the fleet as of 4/14/00



## CONCLUSIONS

In this paper we have covered many of the design problems that were experienced designing a high durability compressor. The resolution of these problems required various design improvements covering a wide array of solutions. These solutions ranged from surface coatings, material and heat treat selection, and also by attention to the design detail itself. The result has been a compressor that has performed very well in the field.

## REFERENCES

- [1] Y. Huang, S. Harte, L. Sud; "Dynamic Parameter Optimization of an Automotive A/C Compressor using Taguchi Method", 1998 International Compressor Engineering Conference at Purdue, P261-266.
- [2] F. Bin, J. Churgay; "A Study on Migration Phenomenon in Automotive A/C systems", 1998 International Compressor Engineering Conference at Purdue, P225-230.

